1.0

2.8

2.5

3.2

2.2

3.6

1.1

4.0

2.0

1.8

1.25

1.4

1.6

MICROCOPY RESOLUTION TEST CHART

UNLIMITED

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A SYSTEM FOR THE PROCESSING, TRANSMISSION AND
REMOTE DISPLAY OF DATA FROM A WEATHER RADAR

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A SYSTEM FOR THE PROCESSING, TRANSMISSION AND REMOTE DISPLAY OF DATA FROM A WEATHER RADAR.

by A. P. Ball, J L Clarke, B D Davy, M J O'Brien, S E Trigg, B C Taylor and T A Voller

SUMMARY

The memo describes a prototype system which has been developed to enable quantitative precipitation data from a weather radar to be made available in timely fashion to meteorologists and hydrologists remote from the radar station. The data is available within 30 secs of its acquisition by the radar and is presented as a colour-coded map showing the intensity distribution of the rainfall over a large area. The display terminal uses a modified colour television set and the transmission is by means of standard PO lines. Other data outputs are available in a computer-compatible format and the system design is such as to allow future expansion to embrace a number of radars and to meet a number of different user requirements.

An experimental system has been implemented at a radar site in N Wales, and is currently transmitting instantaneous rainfall 'pictures' and integrated rainfall totals to the Meteorological Office at Preston, to the Malvern Office of the Severn - Trent Regional Water Authority and to the Bala Office of the Welsh National Water Development Authority.

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1   INTRODUCTION

Radar has long been used by the meteorologist, primarily for the identification
and tracking of hurricanes, tornadoes, thunderstorms, hailstorms, and heavy
rainstorms, but also for the monitoring of less severe weather. It has always
proved a most valuable tool but its widespread exploitation by meteorologists
and others has been greatly hindered by technical and economic limitations
on the timely transmission of even qualitative data from the radar sites to the
potential users. In recent years other important areas of potential utilisation
of radar data have emerged, namely its use for the management of water resources,
flood warning and flood alleviation. These interests have been stimulated
by the results of a variety of research studies and tests (Harrold et al[1],
for example) which have clearly established the ability of radar to measure
rainfall quantitatively.

Meteorologists and the hydrologists probably represent the two primary users
of data from weather radars. However there are many secondary users, for
example aviation, the building industry, electricity generating boards and
hydro-electric stations, who would undoubtedly benefit if data from the
radars could be disseminated in suitable form and in timely fashion. In
the past, radar data has not been available in suitable format to the users
but with modern developments in digital components and techniques, particularly
for data processing and transmission, this situation can now change. The
prospect is now with us of servicing, at a reasonable cost, the needs of a
variety of users remote from weather radar sites.

This memo sets out to describe a prototype system which has been developed
by the Royal Signals and Radar Establishment, Malvern, on behalf of the
Meteorological Office, with the objective, in the first instance, of taking
data from an individual weather radar and displaying it in forecast offices
remote from the radar. However the system has been designed with a view
to a much wider utilisation of the data in the future.

1.1 Accurate Measurements of Precipitation and the need for Signal Integration

In the measurement of precipitation by radar the equation governing the signal
reflected form precipitation has the form

$$Pr = \frac{4.25 \, P_o h}{\theta \, \emptyset \, \lambda^2 \, r^2} \left(\frac{\epsilon - 1}{\epsilon + 2} \right)^2 \qquad \qquad (1)$$

where P_r = average received power   (watts)

P_o = transmitter pulse power   (watts

h = pulse length   (metres)

λ = wavelength   (metres)

$\theta, \emptyset$ = aerial beamwidths (3 dB) in azimuth, elevation (rad)

ϵ = dielectric constant of reflecting particle

and where Z is a measure of the mean signal energy reflected from rainfall
of rate R mm/hr and given by the general relationship.

$$Z = AR^B \qquad \qquad \ldots\ldots\ldots\ldots (2)$$

where A, B are constants with values dependent upon the type of rainfall.
Z is in units of mm^6/m^3

Taking by way of example a C-band weather radar with characteristics given
in Fig 1, we deduce the set of relationships shown there between rainfall
rate, signal to noise ratio, and range.

The figure assumes that rainfall fills the beam at all ranges. In practice
rainfall is of limited vertical extent, and earth curvature will mean that it is
seldom possible to detect significant rainfall areas much beyond 300 Km. It is
evident from the figure that a very wide receiver dynamic range is necessary to
cope with both the spread of rainfall rates and the range dependence of the
signals. The very highest rates of rainfall (100mm/hr and above) will only
occur very occasionally and be very short-lived.

The signals reflected from precipitation are noise-like in character and many
uncorrelated measurements must be averaged before a precise measurement can be
made of the mean signal energy, and therefore of the rainfall intensity. The
set of independent samples are usually obtained by taking samples from a given
pulse volume at different times or by taking samples from a number of pulse
volumes adjacent in range, or both. In the first case (integration in time)
we rely primarily on wind shear and turbulence to redistribute precipitation
particles in the pulse volume between successive independent measurements.
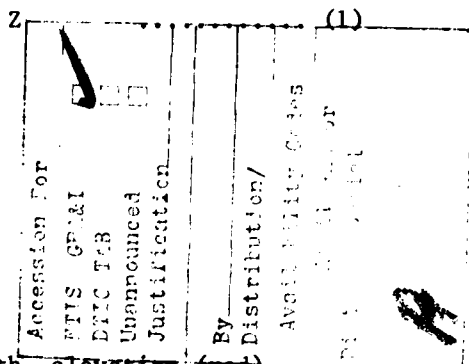
In the second case (integration in range) we exploit the fact that rainfall is generally uniform over many radar resolution cells (typical cell dimension 200-300m), and that measurements taken from adjacent resolution cells are totally uncorrelated at all times.

2
PREVIOUS DEVELOPMENTS IN PROCESSING, TRANSMISSION AND DISPLAY

2.1   Processing

Most previous work concentrated on the basic problem of integration. In the early stages the only integration which took place was that on the face of the PPI tube. Despite an awareness of the potential benefit of integration this situation persisted for some time because of difficulties in implementing integration schemes. In 1959 however Kodaira[2] demonstrated the use of a recirculating analogue delay line for integration in time over 25 consecutive radar transmissions. Integration in range was more difficult and it was not till some years later that suitable equipments were developed (Lhermitte and Kessler 1965[3] for example). Once again analogue techniques were used. Both range and time integration were provided in the Video Integrator and Processor (VIP) designed by the US National Weather Service[4]. Analogue techniques were employed for the integration though the output was quantised in time and amplitude. Each of the equipments made a positive improvement to the clarity of the image on the PPI tube and contributed to a greater ease of interpretation of the display by the meteorologist.

One of the very few attempts to undertake more processing than integration alone was the Storm Radar Data Processor (STRADAP) described by Sweeney[5] (1961). After averaging the radar signals in elements of 1 nautical mile in range by 1 degree in azimuth, the processor carried out a co-ordinate transformation by selecting the maximum value of the elementary averages in a 5 by 5 nautical mile square. For each square a single digit was printed out to represent the maximum intensity in that square according to a scale incrementing in steps of 6 dB. This equipment was among the first to employ a digital approach.

2.2   Transmission and Display

For a long time after the adoption of weather radar as a meteorological tool, the distribution of the radar data was severely hampered by the limited number of transmission methods which was available. When information was distributed from the radar station it represented a very abbreviated and subjective summary of the wealth of information available on the radar screen. Delays in formulation and transmission meant that even such brief messages could not be distributed in real-time. As the demand for radar information in more detail and in real time increased, attention was focussed on to a number of possible techniques for transmission and remote display of the radar data. The simple-minded expedient of transmitting the raw radar signals and constructing the radar PPI presentation remotely for the user was precluded in most cases by the prohibitive costs of the wide bandwidth communication links necessary. Attention was directed instead at the possibilities for economical transmission of more modest but still quite large quantities of data offered by standard telephone circuits. A further important incentive was the potential for widespread availability and utilisation of the data, resulting from the use of the telephone network. The adoption of this approach to transmission however called for (a) methods of making the radar data available for transmission at a rate considerably lower than the

data acquisition rate of the radar and (b) means of reconstructing a radar map remotely from the low bandwidth signals.

One of the earliest solutions to reduction of the data rate was a manual approach in which outline sketches of the radar image were traced on transparent paper overlaid on the PPI tube. Following annotation the sketches were scanned slowly by facsimile equipment and transmitted to remote facsimile recorders. A more significant development was the WBRR system[6] (Weather Bureau Radar Remoting) constructed for the US National Weather Service. This relied upon a storage approach to achieve the reduced data rate necessary for transmission and to reconstruct the radar image on reception. At the radar site the PPI tube was scanned slowly in rectilinear co-ordinates by a Vidicon storage camera and the low bandwidth signal from the camera passed over a telephone circuit. At the receiver terminal a storage tube was used to overcome the problem of slowly arriving data and present a uniform image to the meteorologist. A CCTV system was also employed to scan the storage tube and make the radar data available at a number of different operator positions. This receiver configuration however was subsequently replaced by a conventional facsimile chart presentation for reasons of economy and the availability of hard copy.

2.3   Digital techniques

The equipments and systems reported on above have relied almost exclusively on analogue techniques – analogue integration, scan-conversion, data transmission and display. In view of the known problems of the setting up and the stability of analogue equipments, and the distortion and interference which can corrupt analogue transmissions over telephone circuits, there is a limit on the extent to which we can expect quantitative data from the analogue approach. Furthermore such systems provide data in a form which is not readily amenable to further processing as demanded by particular user requirements. Thus although the approaches outlined above are adequate in providing remotely a general outline of weather situations and in particular areas of severe weather, the further utilisation of the radar data to meet other requirements is sorely restricted. The advent of digital approaches in recent years is altering this situation and is opening the door to more extensive use of the radar data.

The stability and insensitivity to interference of digital processing and transmission systems offer the promise of making quantitative data available in real time to remote terminals. With data available in digital form no limitation on the available display techniques is implied since we can readily convert it back if required to an analogue form for display. However, we realise a number of very important advantages now the data is quantitative and in a form amenable to processing by a computer; for example

    i)   Rainfall accumulations integrated over an area and over a period
          of time can be   evaluated   for hydrogolical purposes.

    ii)   Very short term objective forecasts become possible.

    iii) Data from a number of radars can be composited to give a unified
          presentation of precipitation distribution over large areas.

    iv)   Readily accessible banks of precipitation data can be built up
          for research and climatological purposes.

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One of the earliest attempts to make data available in digital form was the STRADAP equipment mentioned previously. The equipment did not however proceed beyond providing a degree of automatic data processing and a numerical print-out at the radar site, though it had the potential to remote the digital information to a user. Over the last 10 years the field of digital components, techniques and systems has grown considerably, largely stimulated by an expanding computer market. Costs have fallen to the point where we can contemplate much more automatic processing at the radar site than ever before, and produce digital data from the radar in a form appropriate to a variety of user requirements. Digital methods of communication are now available for the widespread dissemination of quantitative data over the telephone network, and new and more attractive techniques of information display can be considered.

3   USER REQUIREMENTS

There are a number of types of information which different users might seek from a weather radar. One such is the three dimensional structure of the atmosphere which is required for storm analysis – for this the CAPPI approach (Constant Altitude Plan Position Indicator) pioneered by Marshall[7] (1957) is most appropriate; other types of information include two-dimensional data on surface precipitation, and RHI sections to determine vertical structure. The flexibility of the computer-based system to be described is such that any of these requirements can be met. However, we have identified surface precipitation data as being of the greatest interest and it is on the acquisition of this information that we focus attention. We have further considered that by providing data to meet the needs of both forecasters and hydrologists we shall also be able to satisfy many of the other potential user needs.

To meet forecasting requirements, what is needed most of the time is not a detailed image of a remoted radar PPI (which will inevitably include unwanted features such as ground clutter echoes and terrain screening effects) but a clear map showing only the distribution of precipitation and the intensities according to a scale of perhaps six levels. A suitable spatial resolution would be some 5 km and a suitable interval between successive rainfall maps would be 15 mins. The hydrologist's needs are somewhat more exacting and call for accurate measurements of rainfall rate to be made every 4-5 mins with many more levels of intensity and with a rather higher spatial resolution (2 km). The primary requirement of the forecaster is for the display of rainfall patterns from one or more radars whereas the primary hydrological requirement is for radar data which can be passed into a computer for the computation of rainfall totals in sub-catchments.

With these observations we can now set down a list of important objectives for the system to be designed:

1   To present quantitative information on rainfall intensity with the required spatial (2 km, 5 km) and temporal (5 mins, 15 mins) resolution to any number of users remote from the radar.

2   To make such data available in a format to enable further computer processing operations as required.

3   To present the processed radar data to the meteorologist as a clear pictorial display.

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4   To design a system capable of extension from the prototype
      configuration into an integrated network for the acquisition of
      precipitation data from a number of radars and dissemination to
      a variety of users, meteorological, hydrological and other.

4   THE RSRE PROTOTYPE SYSTEM

4.1   System configuration and some radar requirements

Fig 2 shows in block diagrammatic format the outline of the system which has
been developed. Two major features should be noted. Firstly the adoption of a
minicomputer to carry out a variety of data processing and organisational
operations at the radar site; and secondly, at the receiver terminal, the
exploitation of colour television for the pictorial display of processed data.

Overall control of system parameters and system functions is by means of
instructions from the operator at the teletype. At the radar data processing
level, for example, the parameters for range and time integration, and the law
for conversion from radar reflectivity to rainfall rate are set from the tele-
type. The form of the output data (resolution in space, number of levels etc)
and the interval between successive transmissions to users are also determined
by operator instructions. So too is the particular type of scan programme
carried out by the aerial.

These few comments suffice to underline the flexibility of the system, a
flexibility which will be particularly advantageous in allowing the determination
of optimum parameters for a future operational system. The computer control of
the system has the further significant asset of compatibility with unmanned
operation of the radar site. In this case operator instructions would be
transmitted over telephone lines from a remote teletype and as well as carrying
out its data processing and dissemination functions the computer would also be
responsible for house-keeping tasks at the station. With the high reliability
which can be expected of modern radar systems such unmanned operation has become
a real and attractive possibility.

Clearly it is desirable to obtain from the radar quantitative data to as long a
range as possible. The ultimate limit on the range of measurement is of course
set by earth curvature. Even with an aerial looking at very low elevation, the
radar beam will be well above the ground at 200 km so that the measurement of
"surface" rainfall at this range is scarcely accurate. A second limitation to
the range of quantitative measurement is the melting layer (bright band) for
once the radar beam starts to intercept this the Z-R relationship referred to
earlier becomes range dependent. With aerials of high vertical resolution
(desirably 0.5 degree), pointing at low elevation a quantitative range of 100 km
may be attainable - at this range the upper 3dB point of the beam will be
around 2 Km altitude for a beam centred on 0.5 degree. To achieve this quantita-
tive range consistently however may call for the implementation of schemes to
correct for the interception of the bright band. We have therefore deduced as
our target quantitative measurements to 100 km, with less accurate measurements
being obtained out to about 200 km. The latter measurements are still adequate
for forecasting for example, but are probably no longer good enough for
hydrological purposes.

As far as the azimuthal beamwidth of the aerial is concerned, it seems sensible
to match this approximately to the more exacting of the spatial resolution
requirements. Thus the 2 km resolution at 100 km required for hydrological
purposes defines an azimuth beamwidth of approximately one degree.

The optimum frequency of operation is felt to be in C-band, between the extremes

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of, on the high frequency side, excessive attenuation of the radar signal in rain and, on the low frequency side, the high cost of large aerials.

With a transmitter power of 250 kw to 1MW, an adequate SNR can be obtained on the lowest significant rainfall rate (0.2mm/hr) out to about 100 Km range. The limited vertical extent of rainfall of this intensity and earth curvature make it pointless to seek better performance.

Fig 1 indicates the capability of a radar system designed along these lines.

It is very evident from the figure that a major requirement on the radar receiver is wide dynamic range. This can only be satisfied by a logarithmic receiver, and even then with some difficulty. The dynamic range required can be eased, and the subsequent data processing load reduced, if swept attenuation is employed to compensate for the $1/r^2$ range dependence of precipitation signals (see equation (1)). An r.f. PIN diode attenuator driver has been designed and implemented for this purpose. It is described here in Appendix 1. For signals normalised to 100 Km, the attenuation introduced at each range from 1-100 Km will be as indicated by the dashed line in Fig 1.

If quantitative measurements of rainfall rate are to be consistently achieved an important requirement on the whole radar system is that of stability, so that once calibrated (by r.f. means or by comparison of radar and telemetered rain gauge data) performance is maintained up to the next calibration. This aspect of system design has been discussed in some detail elsewhere.[8]

4.2   Data Processing

4.2.1   Signal Integration and correction for terrain-screening

Following each radar transmission the aerial receives data from the azimuthal sector of space shown in Fig 3A. The analogue video train from the radar is digitized in the 8 bit analogue to digital convertor shown in Fig 2, which samples approximately once per radar pulse length. Thus the digitiser effectively gates the sector in Fig 3A into a very large number of range cells (typical length 200m). The digitised radar signals are integrated in range by the programmable hardware averager described in Appendix 2. The integration, or averaging, is over a number of radar resolution cells, the precise number being set at 2, 4, 8 or 16 from the computer - the choice could for example depend upon the spatial variability of the rainfall. Following each transmission therefore the range cells are averaged into a small number of bins (Fig 3A) and passed into the computer. Transfers to the computer are by Direct Memory Access.

The averaging of logarithmic signals to determine a mean signal power (and hence a mean rate of rainfall) over an area leads to errors in the presence of strong gradients in the rainfall intensity. Reflectivity gradients of 20dB/Km are not uncommon in convective rainfall situations and this can lead to errors of some 3dB in estimation of mean reflectivity if log signals are averaged.[9] Again,[9] in thunderstorms gradients can exceed 30dB/Km with errors of 6.6dB and above. To avoid this obvious source of error, the hardware averager incorporates a ROM programmed to convert the log L^2 values at its input to L (signal amplitude) and all signal averaging, by hardware and later by software, operates on signal amplitude. In this way gross errors due to spatial (or temporal) gradients are much reduced - to 1 dB and 2 dB, respectively, in the examples quoted above. (The use of the digital anti-log ROM pre-supposes that the receiver characteristic can be held stable to better than $\pm$ 1 dB or it introduces its own error into the rainfall measurement).

Further integration, in time, is carried out within the computer. Not every

transmission from the radar may be useful for this purpose in view of the time required before independent measurements can be made in each range cell. The time to independence is dependent upon wavelength as well as on the meteorological factors of shear and turbulence, as has been discussed for example by Nathanson and Reilly.[10]

For a C-band radar a typical time would be some 12.5 msec, much longer than the pulse repetition interval of the radar. The computer therefore instructs the hardware averager when it is prepared to receive new data from it. Since the aerial is rotating, time corresponds to azimuth and in effect integration in time is integration in azimuth. It seems sensible to match the system parameters by carrying out the azimuth integration over a sector approximately one degree wide (the azimuth beamwidth). At the end of this sector the mean signal in each of the bins is evaluated and a list of these values held in the computer for further processing. Acquisition of data, gating and integration then commences for the next azimuth sector.

The precision with which the mean signal is determined depends upon the number of independent samples integrated. For a given length of range bin, chosen in accordance with a 2 km maximum resolution, this precision depends upon the number of integrations in azimuth, and the number of integrations in azimuth is in turn related to the scan rate of the aerial. Hence the aerial scan rate is directly related to the required measurement precision. For example, if we integrate 8 pulses in azimuth then the time to traverse one degree is 100 msec and the aerial scan rate is approx 2 RPM.

At the end of each azimuth sector a mean value has been determined for the signal amplitude in each polar bin. The first post-integration operation carried out is the adjustment of the list of mean values held in the computer for the effects of obscuration or screening. With an aerial scanning at low elevation to acquire "surface data" the radar beam will almost inevitably be at least partially intercepted by the terrain at some azimuths. In these directions signals from beyond a certain range will be correspondingly reduced, and in the software provision is made to apply an appropriate correction (computed from measured beam and horizon profiles) for such effects to each value in the list.

4.2.2 Clutter removal

Signals from terrain (ground echoes) are removed with the aid of "clutter maps" stored in the computer memory, showing for each aerial scan used the location of bins in which measurements will always be corrupted by ground echo. Values in such bins are rejected and replaced by a computer-derived interpolation between the nearest bins which are free of ground echo.

With an aerial scanning at low elevation to maximise the range to which useful indications of surface rainfall can be provided, there will inevitably be a severe ground clutter problem at short-range. This can be alleviated by performing additional PPI scans at one or more higher elevations to collect rainfall data close to the radar. The system software thus provides for the storage of several clutter maps (one per aerial elevation scan) and for the assembly of complete surface rainfall fields from data collected over several scans.

4.2.3 Collection of Clutter Maps

The clutter maps are produced automatically by carrying out data collection scans in the absence of precipitation, setting a threshold level (by software)

and storing in memory all the polar cells (typically 1° in azimuth, 600m in range) in which the mean signal amplitude exceeds this level. If the clutter threshold is set too close to the system noise level, we may fail to find any "holes" in an extended patch of clutter and the interpolation procedure above will be inaccurate. On the other hand setting the level too high means that all clutter is not accounted for, and some may later be interpreted as areas of rain. The problem is compounded by both the short term (1-10Hz rate) and long term fluctuations (mins to hrs) in the strength of clutter returns. An example of the latter has been a 10dB change in echo intensity of a clutter patch after the passage of shower over it.

In general the clutter threshold has been set at a compromise level, approximately equivalent to the minimum rate of rainfall to be detected (0.1 mm/hr). The "long-term" fluctuation however indicates the need to up-date clutter maps on a regular basis, and the possibility of their collection automatically in the presence of rain is currently been investigated, and is reported on in Appendix 3. The rationale behind the approach is the wide disparity in the fluctuation rates of signals from "fixed targets" and from precipitation. At C-band, for example, fluctuation rates for clutter signals commonly lie between 1-10 Hz, and for precipitation between 100-200 Hz.

Fig 4 shows part of a Clutter Map stored for the C-band, 1.0 pencil beam radar at Llandegla, N Wales. The map refers to a PPI scan at 0.5 degree elevation, and with a clutter threshold level set at -96dbm, some 6-8 dB above noise level and equivalent to 0.1 mm/hr when $Z = 200 R^{1.6}$. The map is organised in memory as a listing giving for each azimuth sector (typically 1 degree) the range bins at which clutter patches begin and end. Range bin numbers are given here in octal and based on a bin size of 600m. 000 signifies no further patch of clutter along a given azimuth and signals the start of data for the next sector.

4.2.4 Conversion to Rainfall Rate, Attenuation Correction and Co-ordinate Transformation

Having processed the data to remove terrain effects we are in a position to convert the list of digitised radar amplitudes into a list of digitised rainfall rates. This is achieved by reference to a table generated from a relationship between radar reflectivity and rainfall rate. The calibration law is determined by the computer by interrogating a telemetering raingauge and comparing the raingauge data with radar signal amplitudes measured over the gauge. A value of 1.6 is taken for the index B in equation 2. A number of telemetering raingauges are required for very accurate measurements over large areas ($10^4 Km^2$) and different relationships can be applied for different regions in the field of view of the radar.

Significant attenuation of radar signals may occur where the beam passes through an extended belt of moderate rain or localised areas of very heavy rain. Rainfall rate-attenuation relationships are however fairly well established[11] and this is a source of error in the quantitation measurement which we may largely avoid. Since a figure for rainfall rate must be available before we can calculate a corresponding attenuation, the correction applied for rainfall attenuation is closely coupled with the conversion from signal amplitude to rainfall rate above. We assume that rainfall is accurately known in the range cell closest to the radar. The attenuation through this cell is computed and used to correct the radar signal amplitude measured for the second cell, leading to a corrected rate of rainfall for the second cell. This corrected value is used in turn to compute an attenuation which is used to modify the signal amplitude and hence rainfall rate in the third cell, and so on out to maximum range.

The final stage of processing is to convert the data into a cartesian form by transferring the contents of the list into the appropriate cartesian boxes of an output grid, as shown in Fig 3B. As the aerial scans past each cartesian box it will receive contributions from a number of polar bins and the rainfall value finally stored in a particular box when all contributions have been made is arrived at by simple averaging.

At the end of the PPI data collection scan(s) all the boxes are filled and the digitised precipitation data is ready for dissemination over telephone circuits to the users. Two data output grids are formed and are illustrated in Fig 5, 6. The first has a spatial resolution of 5 km and contains rainfall values quantised into 3 bits - this is transmitted at intervals of 15 mins or so and is displayed pictorially in forecasting offices. The example given refers to data collected and processed at a radar site in N Wales, and shows the rainfall distribution at 15.31 GMT on 14.5.75. The rainfall code is indicated on the figure caption. The high resolution grid of Fig 6 is provided for users interested in the detailed structure of precipitation. For hydrology applications the data is integrated in time and over sub-catchment areas to determine sub-catchment rainfall amounts for use by river engineers. Fig 7, for example, indicates some of the sub-catchments of the Severn basin together with the 2Km grid. Half-hourly rainfall inputs to each of these sub-catchments is currently being transmitted to the Severn-Trent Water Authority from the experimental radar installation in N Wales. The same site is also providing similar real time data for a computer at the River Control Centre at Bala, N Wales, which is predicting flow in the River Dee.

4.3   Receiver Display Terminal

With no reason to transmit a given data grid to users more than once, and every reason not to do so (since it implies immobilising a telephone circuit unnecessarily), some form of storage is clearly called for at the receiver. In previous approaches such storage was provided either by a storage tube[6], by a facsimile recorder[11] or by teleprinter (McGrew 1972); a high speed line printer is another possibility. None of these was however deemed acceptable - the storage tube because of the difficulty of obtaining more than 3 or 4 distinguishable levels of intensity and because of its expense for reasonable sizes of screen, the facsimile recorder and the teleprinter for their low speed of operation; and the high speed printer because of expense. Instead we were attracted by the possibility of using a semiconductor store to produce a suitable display on a cheap, commercial colour television, slightly modified. Such a display appeared to offer a number of advantages - clarity of presentation, with each of the seven rainfall levels represented by a particular colour or shade; a large screen; the ability to operate a number of displays in parallel in view of the low cost of the televisions themselves, and the ability to operate in normal room lighting.

To display even a static picture on the television screen, the data store had to supply a continous output of data at MHz rates, and the semiconductor storage elements with that capability and at an acceptable cost had only recently (in 1972) become available. Indeed their advent (predictably) forced down the cost of magnetic stores which, but for cost, might have encouraged such an application at a much earlier time. Of the several types of semiconductor element which were suitable for the construction of such a store, we selected the dynamic shift register (DSR) type as the cheapest appropriate device at the time, although later versions of the data store ordered from 1975 onwards used static random access memory (RAM) type storage elements. At that time the RAM, due to commercial pressure from the computer industry, had emerged as the

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popular replacement for the DSR and was therefore cheaper.

In addition to its task of continuously supplying the television with repetitious
data at MHz rates to keep a static picture alive, there was also the fact that
the input data rate to the data store from the telephone circuit modem was
600 bit/sec, so the store had also to perform the task of low-high input
data rate interface. A general schematic of the complete receiver terminal is
outlined in Figure 8A showing that a buffer store is filled with "packets" of
low speed data, which are held there until the appropriate part of the store is
ready to be addressed. At that moment the contents of the buffer store are
then transferred at MHz rate to the main memory, overwriting any previous data
held in that location, and the new "packet" of data appears on the television
screen. The buffer store then continues filling with the next "packet" of low
speed input data, and when full, transfers that data to the next consecutive
location in the main memory. This process continues until a complete new
picture is formed.

The size of these data "packets" varies between the DSR type stores and the RAM
type. In the case of the DSR type store, displaying data on a grid of 84 x 84
squares, the "packet" contains 84 bits, ie one complete line of data. Therefore
a new picture being updated into store builds up on the television
screen as one complete line at a time with an input data rate of 600 bit/sec,
a new picture takes about 30 seconds to form. An 84 x 84 picture on a RAM
store takes the same length of time to form, but the data "packets" consist of
only 8 bits, hence the picture forms in a rippling scan fashion
rather than in the definite line by line manner of the DSR store. The picture
finally displayed is the grid of figure 5, with each box containing a specific,
but abitrarily selectable colour which has been allocated to it.

Although the simplified schematic diagram figure 8A details only one buffer
store and one main memory, these are both triplicated within the stores to
provide separate storage for red, green and blue data. These colours, displayed
singly or in their four possible colour combinations - yellow, purple, cyan and
white with the addition of black for zero rainfall data, are used to present
the seven rainfall levels on the television screen. The outputs from the red,
green and blue data memories are fed into a colour interchange circuit which
allows any one of the seven available colours and black, to be selected manually
by the store user to represent any level or group of levels of rainfall rate.
Hence any one of the seven rainfall levels can have an arbitrarily selectable
colour on the television screen, and if a single colour is used to represent
two or more consecutive levels of rainfall, a visually simplified display of the
data is available. Figure 9 shows a rainfall situation detected
by a radar site at Llandegla in North Wales on 15 November 1975, and is
displayed in a simplified form.

Figure 8B shows the organisation of the data received from the telephone
circuit modem. Each eight-bit information byte is enclosed by a start bit and
a stop bit.

The bytes are arranged to give two 3 bit colour words of data, where each
colour word defines the rainfall value and therefore the displayed colour of
one of the squares on the 84 x 84 grid. The two spare bits of the data byte
are given the logical value 0, to identify the byte as a data byte. The data
stream received by the store has periodic frame and line bytes in addition to
the general data bytes referred to above. The purpose of the frame bytes is
to inform the main memory input/output control logic that the data about to
appear is at the beginning of a new picture. Therefore this data must be entered

12

into the memory location corresponding to the top of the displayed picture. From then onwards the following data stream is entered into consecutive locations in the memory thereby ensuring correct registration of the data on the television display. With some exceptions, the stores are designed to store nine separate 84 x 84 pictures. The main memory is matrixed in a pattern which enables the incoming data to be routed to a specific memory location, allocated a frame number from 1-9 inclusive. When a sequence of nine different pictures is received, each successive picture has the next consecutive frame number in the 1-9 sequence and therefore is entered into the next consecutive location in the memory matrix; a tenth picture would have the same frame number as the first picture received and would therefore overwrite that picture in the memory. The frame byte is arranged with the four least significant bits giving the frame number, and the remaining four bits set to a logical 1, to constitute the frame byte identification code.

The line bytes occur after every 84 colour words, (42 bytes), received in an 84 x 84 picture. They are important to the operation of the DSR type stores for the correct synchronisation of the entry of data into the main memory. In both the DSR and the RAM stores, the line bytes are also used to increment a front panel visual display of the number of the data line currently being updated. Both frame and line bytes, when transmitted, are sent three times, and parity checking circuits in the data decoders need to recognise the same code at least twice before allowing a frame or line byte to be decoded. This is a precaution against the recognition of spurious frame byte codes, line byte codes or incorrect frame numbers due to data corruption along the telephone circuit.

A MHz rate master clock in the timing circuit synchronizes the waveforms for controlling the entry, output, and in the case of the DSR stores, the recirculation of data in the main memory. The timing circuit also provides television synchronising waveforms and drives the circuits which generate the static features on the display, ie map, 100 Km grid and crosswire. The grid and crosswire are generated directly from these continuous waveforms, the crosswire co-ordinates being manually set by thumbwheel switches. A set of read only memories (ROMs) is addressed by these waveforms to produce a static map of the geographic features of the area covered by the radar.

Long-term storage of large numbers of pictures can be made at the receiver by making audio recordings of the telephone circuit transmissions on a cheap cassette recorder. The data from audio tape can then be re-played into the data store via a modem similar to the GPO modem used to demodulate the the original audio transmissions. Automatic switching on of the tape recorder at the start of a picture transmission and switching off at the end is controlled remotely from the radar site, by preceding the normal frame bytes at the start of a picture with another set of three frame bytes having a coded frame number 10. Frame number 10 is not recognised by the main store circuits, but is recognised as a "switch on" command to the tape recorder. Similarly, at the end of a picture transmission, a frame number 11 command is sent to switch off the tape recorder.

The data stores as described were designed to display nine pictures on an 84 x 84 five Km grid. If, however, a greater radar operating range has to be displayed, or if greater resolution is required, it is a simple matter with the same size memory and minor changes to the control logic, to use the data stores to display either a single picture on a 256 x 256 grid, or perhaps 4 separate pictures on a 128 x 128 grid.

At the time of writing, five data stores are in operation. One is driving the

on-site display at the Llandegla radar site, the other four are driving displays at the following locations: WNWDA (Bala), Met Office (Preston), Severn-Trent River Authority (Malvern) and RSRE (Malvern). The stores have been constructed under contract by Jasmin Electronics Ltd according to an RSRE design which has evolved in the light of operating experience. The design has now been frozen and additional stores can be supplied by the firm at short notice.

5   CONCLUSIONS

A computer-based system has been described which can make available in real time and to any number of users accurate digitised data on precipitation intensity within some 100 km of the radar, and qualitative data out to some 200 km from the radar. The data can be made available in a form suitable for further computer processing or for logging, or as a clear display in up to seven intensity (colour) levels on a modified colour television. The modest cost of the complete terminal (£3500) should encourage its widespread adoption in the future. Acquisition of the radar data by the system takes up to one minute and since the processing and acquisition operations proceed in parallel, the processed data is available over telephone lines almost immediately after the completion of the acquisition cycle. A pictorial display of the weather situation can be presented wihin 30 secs on any number of remote television terminals.

The display data distributed from any operational radar site implemented with the system could be transmitted to meteorological forecast offices, river authorities, and to other interested bodies such as local authorities, building firms, local airfields, television authorities, etc. The time-lapse facility provided by the terminal may enable forecasters to make precise and accurate judgemeits on the weather in specified areas for an hour or two ahead.

If implemented more widely, on a number of radars with overlapping cover, ie as an integrated network, the individual site outputs could be channelled together to a central computer and composited to give precipitation distribution on perhaps national scale.

6   ACKNOWLEDGEMENTS

The author would like to thank Dr K A Browning and the staff of the Meteorological Research Unit at RSRE for their support and advice. Thanks are due also to the staff of the Llandegla Research Station for their co-operation during the evaluation of the prototype system.

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A PROGRAMMABLE r.f. SWEPT ATTENUATOR

For beam filling meteorological targets, signal strength falls with range as $1/r^2$. It is an effect which has to be compensated for if quantitative measurements of rainfall rate are to be made, and there is no good reason to place the burden for such a well defined and repetitive processing load on to the system software. Correction is therefore made by hardware, and carried out at r.f. so that receiver dynamic range requirements are minimised and a range-dependence of the system noise level is avoided.

A standard PIN diode attenuator is used to provide up to 36 dB of attenuation. Having decided the range r_n to which signals are to be normalised (ie the range at which attenuation is 0 dB), the attenuation required at all other ranges is determined. For example, at range r, an attenuation A dB is called for (see Figure 1.1) and, from the measured PIN diode characteristics (Figure 1.2) we deduce that a current I mA is required. The total range of interest is divided into range cells and information on the current required for the appropriate attenuation in each cell is held in a ROM. The number of range cells required is set by the accuracy demanded of the $1/r^2$ characteristic. In view of the other system inaccuracies we have taken 256 cells to be adequate, corresponding to a maximum quantisation error of $\pm$ 0.6 dB.

The PIN driver logic circuit is shown in Figure 1.3. Following initialisation, a series of clock pulses builds up a range count used to address the programmable ROM which provides the required output to the D to A converter driving the PIN diode through a series load. A divider circuit provides four possible clock rates and hence four possible values of r_n - 200 Km, 100 Km, 50 Km and 28.5 Km.

The transmitter pulse is obtained from the radar trigger unit and applied to the input circuit which converts the pulse to the required TTL negative logic. In the normal state the Reset B/S holds both the Var $\div$ and the 8 bit binary counter in the reset condition. On receipt of a transmitter pulse the Reset B/S changes state allowing the Var $\div$ to pass clock pulses at a rate determined by the range switch. The 8 bit binary counter counts these pulses on a 'ripple through' basis until the counter is full (all outputs at logic high). At this point the eight input nand gate triggers the 1.4 mS monostable which in turn switches the Reset B/S. The Var $\div$ is now reset thus inhibiting further clock pulses. The eight bit binary counter however remains in its full state for a further 1.4 mS until the 1.4 mS. M/S allows it to be reset and its outputs assume low condition. Thus, commencing with each Tx pulse the binary counter counts from binary 0 to binary 255 in a time

$$t = \frac{\text{Var} \div \text{rate} \times 255}{\text{Clock freq}}$$

determined by

determined by the clock frequency and Var $\div$ rate (4, 7, 14 or 28). The counter then remains at 255 for a further 1.4 mS (210 km radar range) before returning to binary 0. The count is applied to the address inputs of the read only memory which is programmed such that the corresponding word outputs follow the required $1/r^2$ law. It is necessary to strobe the memory outputs so that the D/A converter does not see the glitches which occur during memory access time. This is accomplished during count time by using a Var $\div$ output to fire the 200 nS M/S which enables the latch only during memory hold time. An output from the 1.4 mS M/S performs the same function when the count goes from 255 to 0. To further ensure that minimum attenuation is obtained between r_n and r_n + 210 km the 1.4 mS M/S output is also used to deselect the memory during this period.

Deselecting the memory is also the means by which minimum attenuation may be obtained by computer control without disturbing the count sequence. The voltage output from the D/A convertor is fed to the pin diode (current operated device) via a series load.

TEST FACILITY

The test B/S enables single pulses to be applied to the counter by pressing the push button switch thus any programmed word can be selected by pushing the button the number of times corresponding to the required address.

Thus if :-

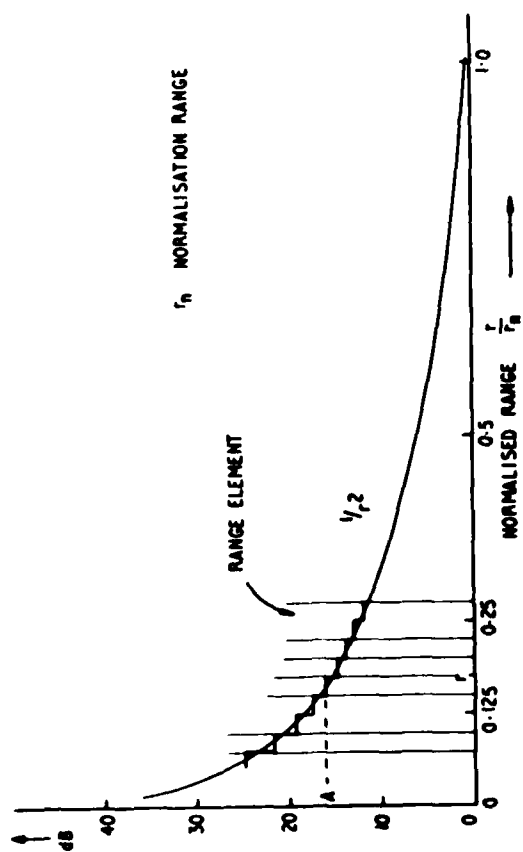|			
Add	0	=	-36 dB
then add	7	=	-30 dB
add	15	=	-24 dB
add	31	=	-18 dB
add	63	=	-12 dB
add	127	=	-6 dB
add	255	=	0 dB

FIG 1.1.
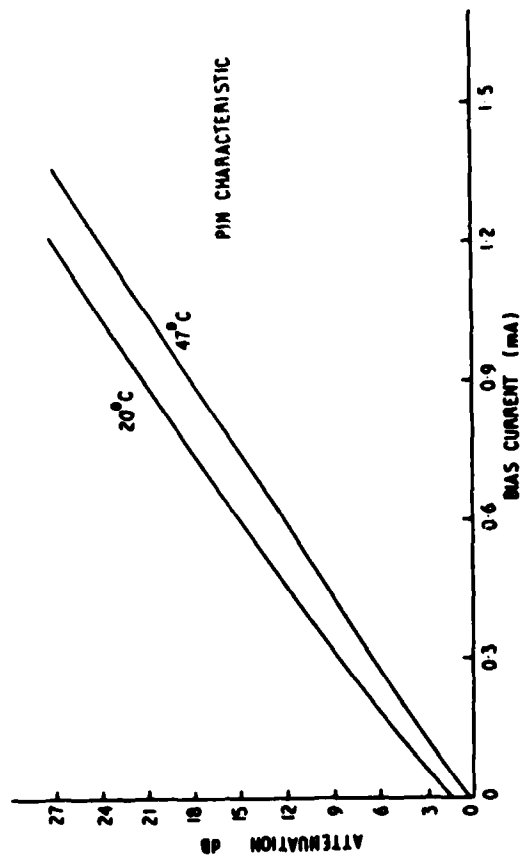ATTENUATION vs NORMALISED RANGE FOR A PIN DIODE ATTENUATOR

FIG. 1.2.
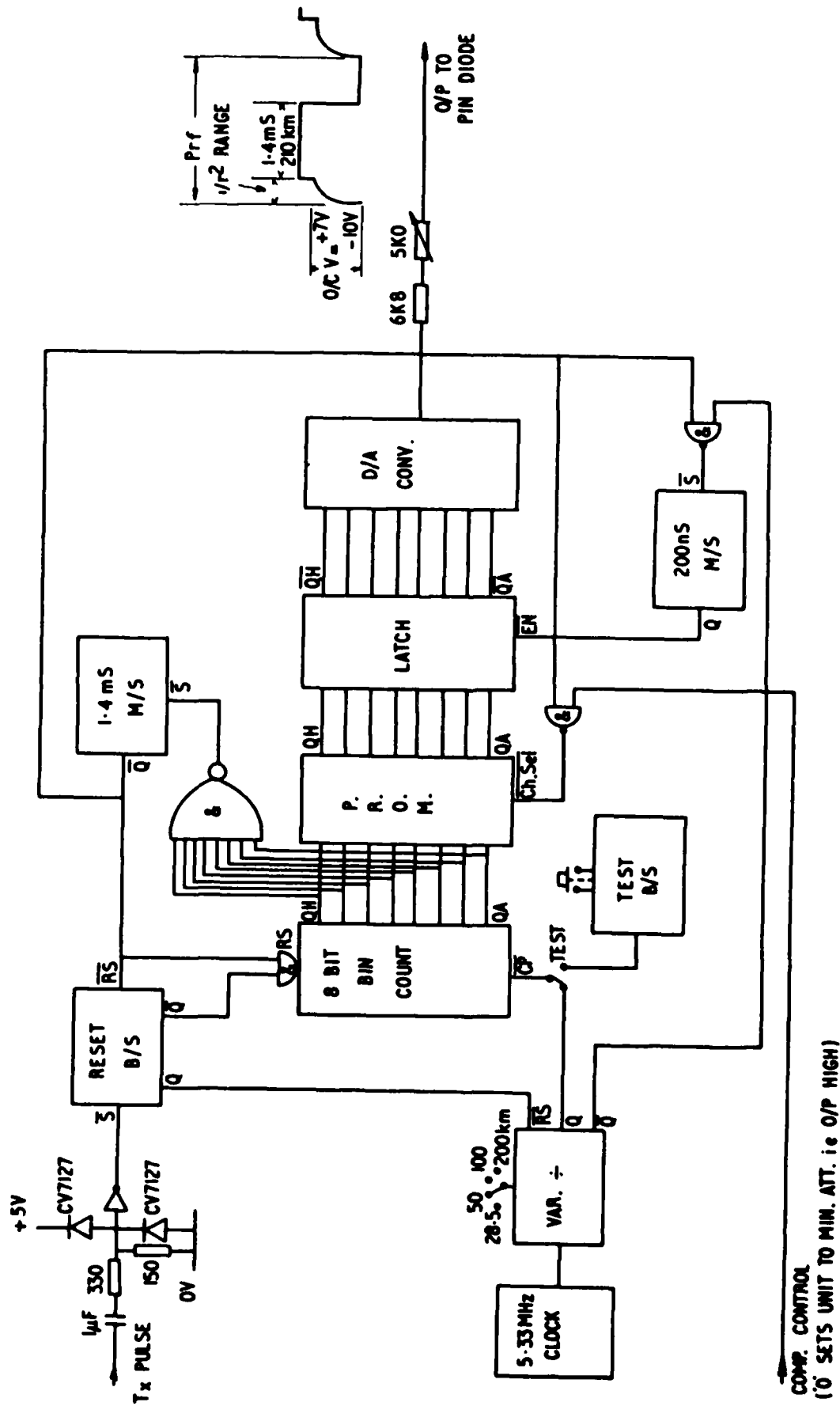ATTENUATION vs BIAS CURRENT FOR A PIN DIODE ATTENUATOR

FIG. 1.3.

PIN DIODE DRIVER LOGIC CIRCUIT

RR/R 31/9987

COMP. CONTROL
('0' SETS UNIT TO MIN. ATT. ie O/P HIGH)

APPENDIX 2

ANTI-LOG GENERATOR AND PROGRAMMABLE RANGE INTEGRATOR

This sub-system is responsible for digitising anti-logs, signal averaging (in range), and delivering the processed data by Direct Memory Access to a PDP-11 computer. Fig 2.1 gives an outline of the unit.

The log video signal is digitised to an 8 bit form by an ADC operating at a rate set by a train of clock pulses from the radar system (normal rate 1 MHz). A programmed ROM generates a 12-bit antilogarithm (the normalised radar signal amplitude L) at intervals of 1 μsec. The ROM look-up table is implemented using 2 x 2048 bit erasable MOS devices.

Successive words from the anti-log generator are summed in an averaging store. This is a one word by 16 bit storage register. After a pre-set number (1-16) of samples have been summed the content is transferred to a holding register, the store cleared and new averaging commenced. The holding register contents are transferred to a computer. The pre-set operation is accomplished by a computer output instruction.

The input-output law for the antilog ROM follows from the log receiver character-istic. Fig 2.2 shows a typical characteristic and the ROM law is determined by the vertical scales Digitised Log Video and Normalised Signal Amplitude. In this case signals have been normalised so that $L = 1(4)$ corresponds to $P_r = -102$ Bm (-96 d Bm).
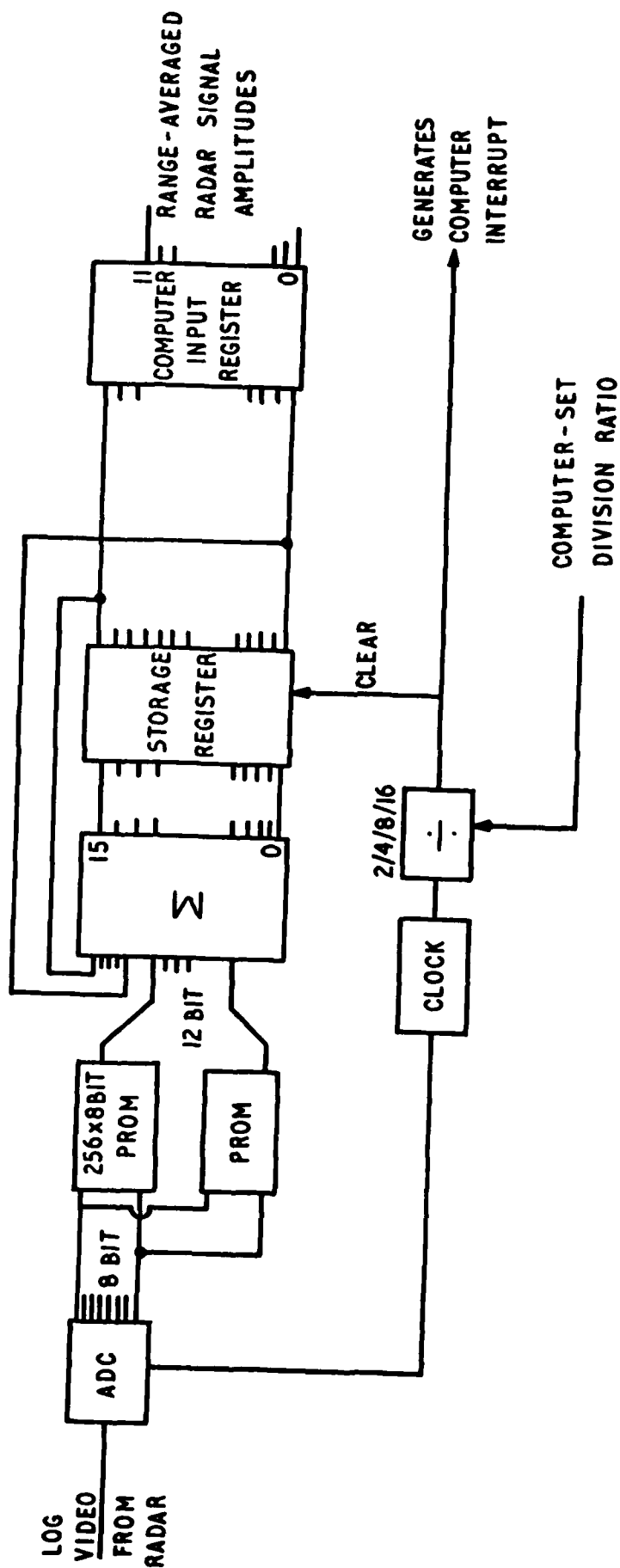
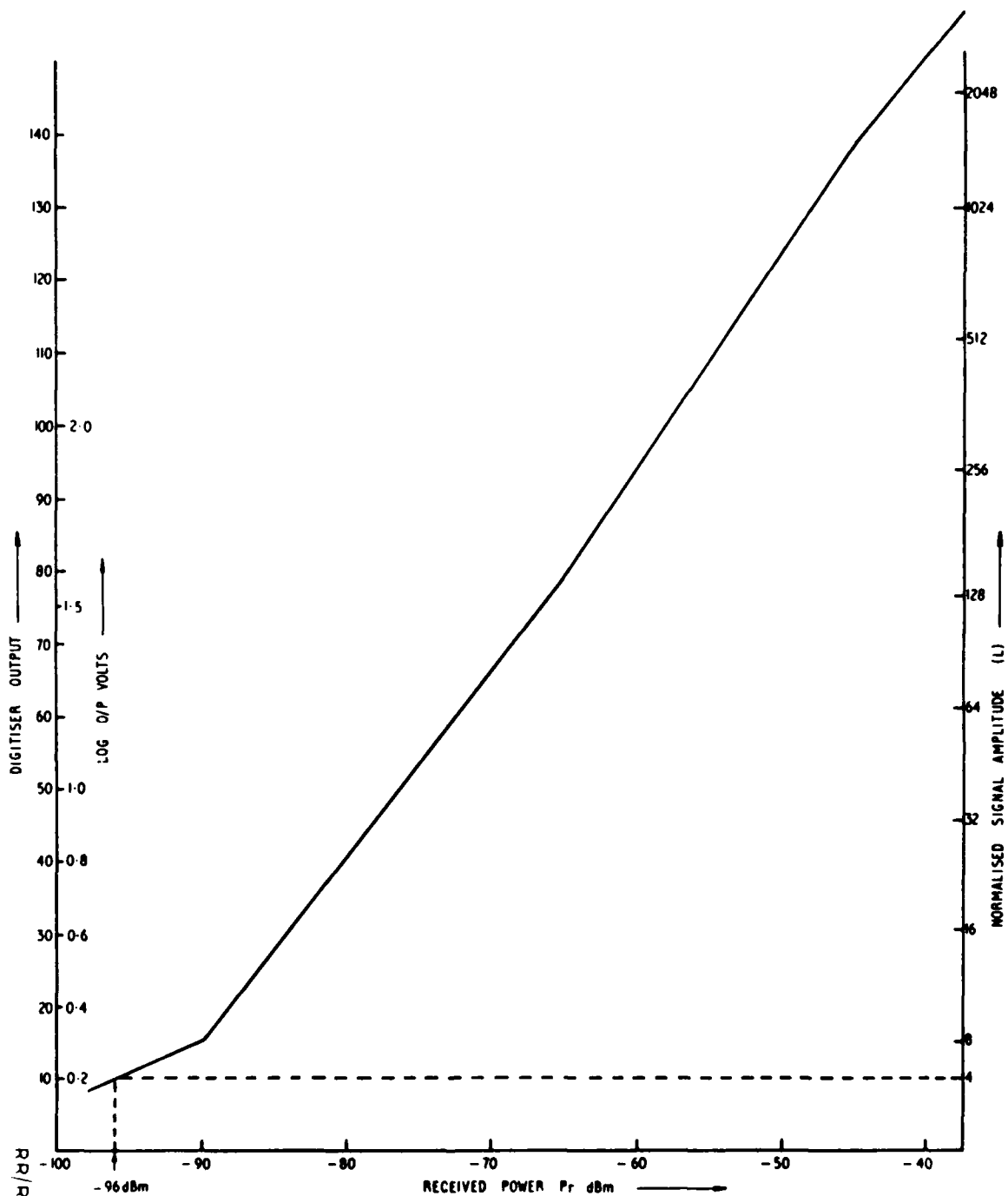FIG. 2.1

PROGRAMMABLE RANGE AVERAGER.

FIG 2.2.
LOGARITHMIC RECEIVER CHARACTERISTIC

RR/R 31/9088

APPENDIX 3

AN IMPROVED TECHNIQUE FOR CLUTTER DISCRIMINATION

The success of the system described depends to a large degree on the extent to
which ground clutter echoes can be recognised and rejected by the data processing
system. So far this 'recognition' has been based on mapping from time to time
the location of the fixed echoes observed by the radar in the absence of
precipitation. This relatively unsophisticated approach has proved to be
remarkably successful and, for at least 80% of the time, the processed data
presented on the system display has shown no trace whatsoever of non-precipitation
echoes.

We can only expect the approach to be successful in so far as the clutter map
in use is representative of the prevailing clutter situation. Although many
ground echoes are 'fixed'and will be successfully handled by the current
approach, other areas may appear or disappear depending upon factors such as
propagation conditions, wetness or dryness of the ground target etc. Slow
variations (days and months) we may expect to be able to take account of by
regular up-dating of the fixed echo maps. It is the short-period variations
which pose the great problem, and the two factors noted above are among these.

The importance of not classifying areas of ground echo as precipitation is made
most clear when we calculate an equivalent rainfall rate of over 100 mm/hr for
many echoes from the mountains adjacent to a weather radar site in N Wales.
This could introduce very serious errors, particularly where fully automated
'rainfall' data handling procedures are employed.

On the basis of experience, the fixed echo map has to be regularly up-dated at
intervals of 15 mins or less, if errors from this source are to be insignificant.
This implies an ability to map ground echo even in the presence of precipitation.

With a coherent radar, we could expect to substantially resolve the problem by
low pass filtering and thresholding to separate out the fixed echoes. A problem
may however arise with precipitation on a tangential track being falsely
classified and leading to the loss of good precipitation data over an area
determined by the tangential velocity and turbulence of the rain area, and the
LP filter characteristics.

A conventional weather radar will be non-coherent and alternative means must be
sought to discriminate between ground and precipitation echo. Possible methods
might be:-

  1) The use of circular polarisation

  2) Area MTI

  3) To exploit differences in ground and precipitation PDFs (probability
      density functions)

  4) To exploit differences in signal fluctuation rates.

Discussing each of these in turn:-

1) It is known that signals from precipitation can be reduced in magnitude by
    some 10-20 dB when circular polarisation is employed. Many land targets,
    on the other hand, are little affected. Unfortunately some of the more

important targets (electricity pylons, metal buildings) give multiple-bounce returns and are consequently polarisation sensitive. Another consideration which makes circular polarisation unattractive is the expense of providing for it.

2) Area MTI is not a viable approach because in some circumstances the area from which ground echoes are observed does move. A case in point is where the echoes are due to anomalous propagation induced by the cold outflow from a thunderstorm.

3) Precipitation returns are composed of reflections from many individual and randomly moving scatterers. The return is thus noise-like and signal amplitudes conform to a Gaussain PDF. Many ground echoes however are dominated by reflections from a few large and fixed targets (pylons, buildings). These exhibit a PDF heavily biassed toward the amplitude of the fixed targets. Fig 3.1 indicates the different shapes of the PDFs which might form the basis of a discrimination technique. Other ground targets, however, are primarily composed of many reflections from targets of like amplitude (eg wood, field). These have PDFs of near Gaussian character and render the PDF approach unattractive.

4) Although the PDF of some ground targets will be the same as for precipitation, the rate at which the range of amplitude possibilities is covered will usually be very much less for the ground target. Furthermore since we are using a logarithmic receiver the fluctuating component of receiver output will have the same excursion for a Gaussian signal, regardless of the mean signal strength. We can therefore think in terms of a very simple clutter/precipitation discriminator which determines a mean pulse-to-pulse change in output signal and compares this value with some threshold level which ground clutter is very unlikely to exceed. As Fig 3.2 shows we wish in effect to look at the average slope of the log L^2vs time characteristic for each resolution cell.

As for the non-Gaussian ground clutter, we can represent this by a fixed echo component (due to pylons, rocks etc) with superimposed random fluctuations (trees, fields etc). The former will come through the receiver as a fixed or very slowly varying dc level and is very unlikely to confuse the discrimination circuitry. The latter will input a Gaussian signal to the receiver and a corresponding log-Gaussian output to be handled as other purely Gaussian clutter.

DISCRIMINATION BY FLUCTUATION RATE

For simplicity assume a sampling period equal to the clutter decorrelation period. This would on average give a pulse-pulse dB change $\overline{\Delta}_{av}$ dB determined by the Gaussian distribution.

If instead we sample at the decorrelation rate of precipitation, which is N times higher, we might expect a pulse-to-pulse average of order $\dfrac{\overline{\Delta}_{av}}{N}$ dB for the clutter difference signal.

The precipitation signal will however still be $\overline{\Delta}_{av}$ dB. Hence we have an approximate ratio of N between the precipitation and ground signals, and we can devise a simple circuit to exploit this difference. The circuit is shown in Fig 3.3. It consists of an A/D converter to digitise the log video signal in each of m range gates r (in the circuit shown m = 256), two small DSR stores to

hold values from the current and the previous radar pulse period, a subtractor to calculate the modulus of the pulse to pulse difference for each of the m range gates, a summer to integrate these differences over n measurements, and a threshold circuit set to identify those range gates in which the integrand does not exceed a level T (this being taken as the level which clutter signals are very unlikely to exceed).

In fact at the present stage where the performance of this circuit is being evaluated, all integrands are read into a computer to investigate the statistical magnitudes of signals from ground and precipitation, prior to determining optimum threshold conditions.

The success of such an approach hinges on three factors:-

i)   the magnitude N of the clutter to precipitation decorrelation rate

ii)   the setting of the threshold condition in Fig 3.3

iii)   the amount of integration – the more, the better the measure of $\bar{\Delta}$, and the fewer the number of false classifications.

Points (ii), (iii) are under our control, so we can determine an optimum setting for the threshold and by integrating sufficiently in time (ie scanning sufficiently slowly in azimuth) and possibly by some scan to scan integration we can expect to obtain adequate measures of $\bar{\Delta}$. The limitation on the method is rather set by (i), which is fundamental and outside our control.

DE-CORRELATION TIMES FOR GROUND ECHO AND PRECIPITATION

Published data usually relates to measurements of clutter spectra, but the following analysis will help us relate these to data de-correlation times:-

The auto-correlation function for a function F(t) is defined by

$$R(t^1) = \frac{\int_{-\infty}^{\infty} F(t)\, F(t+t^1)\, dt}{\int_{-\infty}^{\infty} F(t)^2\, dt} \qquad (1)$$

and from the Wiener-Khintchine theorem the power spectral density G(f) is given by

$$G(f) = \int_{-\infty}^{\infty} R(t^1)\, \exp(-jwt^1)\, dt^1 \qquad (2)$$

and by the duality of Fourier transforms

$$R(t^1) = \int_{-\infty}^{\infty} G(f)\, \exp(jwt^1)\, df \qquad (3)$$

For Gaussian spectra

$$G(f) = \left\{ \exp \quad -0.7 \left(\frac{2f}{\Delta f} \right)^2 \right\} \tag{4}$$

where Δ is the half-power bandwidth.

From (4) and (3) we find

$$R(t^1) = \Delta f \sqrt{\frac{\pi}{2.8}} \quad \exp \left\{ - \frac{(2\pi t^1 \Delta_f)^2}{11.2} \right\} \tag{5}$$

which, in normalised form, is

$$R(t^1) = \exp \left\{ - \frac{(2\pi t^1 \Delta_f)^2}{11.2} \right\} \tag{6}$$

Taking the decorrelation time τ to be that at which $R(t^1) = 1/e$, we have

$$\tau = \frac{0.53}{\Delta f} \tag{7}$$

Expressing this instead in terms of the rms spectral spread σ Hz

$$\tau = \frac{0.625}{\sigma} \tag{8}$$

From measured data quoted by Nathanson[1] we deduce that for σ_g, the standard deviation of the ground clutter spectrum, the following approximate relationship applies

$$\sigma_g = .0075 \ W^{1.3} \quad Hz \tag{9}$$

where W is wind speed in m/sec.

Hence

$$\tau_g \stackrel{\simeq}{} \frac{40\lambda}{W^{1.3}} \quad sec \tag{10}$$

which at C-band (5 cm) becomes

$$\tau_g = \frac{2}{W^{1.3}} \quad sec \tag{11}$$

The standard deviation of the precipitation spectrum is determined by four main factors - vertical wind shear, turbulence, variation in particle velocity with azimuth, and variation in particle fall speeds. The latter two prove to be insignificant for narrow beam (1-2 degree) aerials scanning at low elevation angles.

The precipitation spectrum width σ_p thus depends on contributions from

<u>turbulence</u> σ_t = 1.0 m/sec typically (Ref 2)

and <u>wind-shear</u> σ_s = 1.68 rϕ typically (Ref 2)

the latter being determined by $r\emptyset$, the vertical extent of the beam between the half power points. σ_p m/sec will be given by $\sqrt{\sigma_t^2 + \sigma_s^2}$. Thus

$$\sigma_p = \sqrt{1 + (1.68r\emptyset)^2} \quad \text{m/sec} \tag{12}$$

for which σ_p Hz $= \frac{2}{\lambda} \sqrt{1 + (1.68r\emptyset)^2} \quad \text{sec}^{-1}$ (13)

and

$$\tau_p = \frac{0.625 \ \lambda}{2 \ \sqrt{1 + (1.68r\emptyset)^2}} \quad \text{sec} \tag{14}$$

For C-band (5cm) and for a vertical beamwidth of $\frac{1}{56}$ radian (1 degree) we deduce that

$$\tau_p = \frac{1.56 \times 10^{-2}}{\sqrt{1 + (.03r)^2}} \quad \text{sec} \tag{15}$$

From equations (11), (15) we can plot τ_g, τ_p as functions of range and windspeed (Fig 3.4). From this it can be seen that N^p will usually take values exceeding 5-10, particularly at ranges beyond 50 km, and the approach appears very promising.

AERIAL SCAN RATE

The above has strictly only applied to the case of a stationary aerial. For a moving aerial clutter decorrelation time will be reduced by the contribution to decorrelation from the translation of the radar beam. Every beamwidth movement will produce an essentially decorrelated clutter measurement. If this effect is not to seriously effect the favourable conclusion drawn from Fig 3.4, the aerial should not traverse a beamwidth in much less than 200 mec ie with a one degree aerial, the scan rate should not exceed 1 rpm or so.

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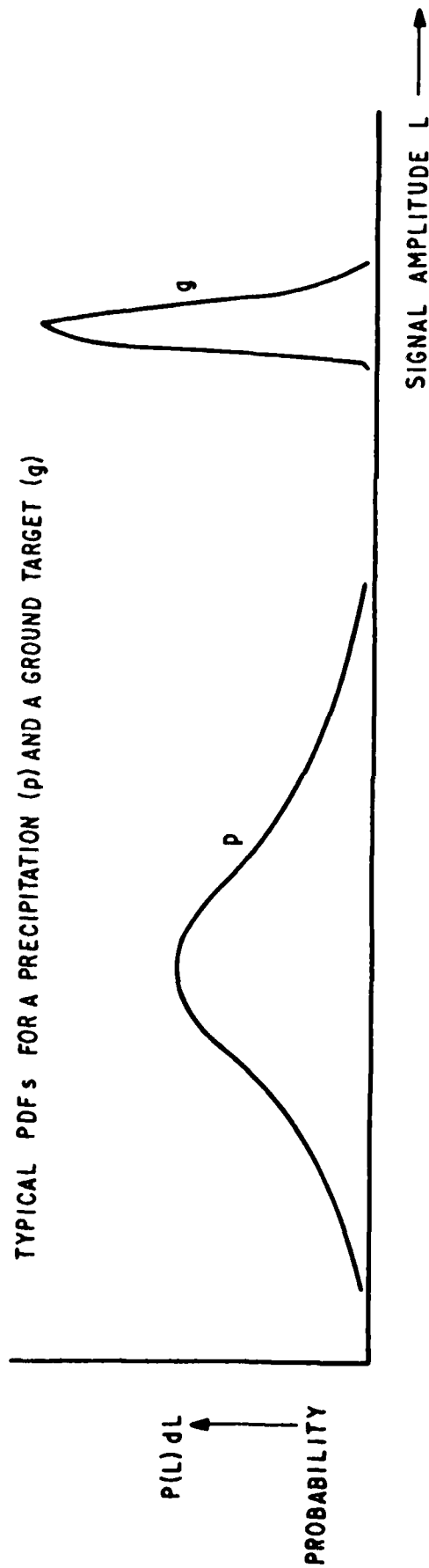2. Nathanson, F E, Reilly, J P, IEEE Trans Vol. AES-4 No 4, July 1968 pp 505-514.

TYPICAL PDFs FOR A PRECIPITATION (p) AND A GROUND TARGET (g)

FIG. 3.1

TYPICAL PROBABILITY DENSITY FUNCTIONS (PDF's) FOR PRECIPITATION AND
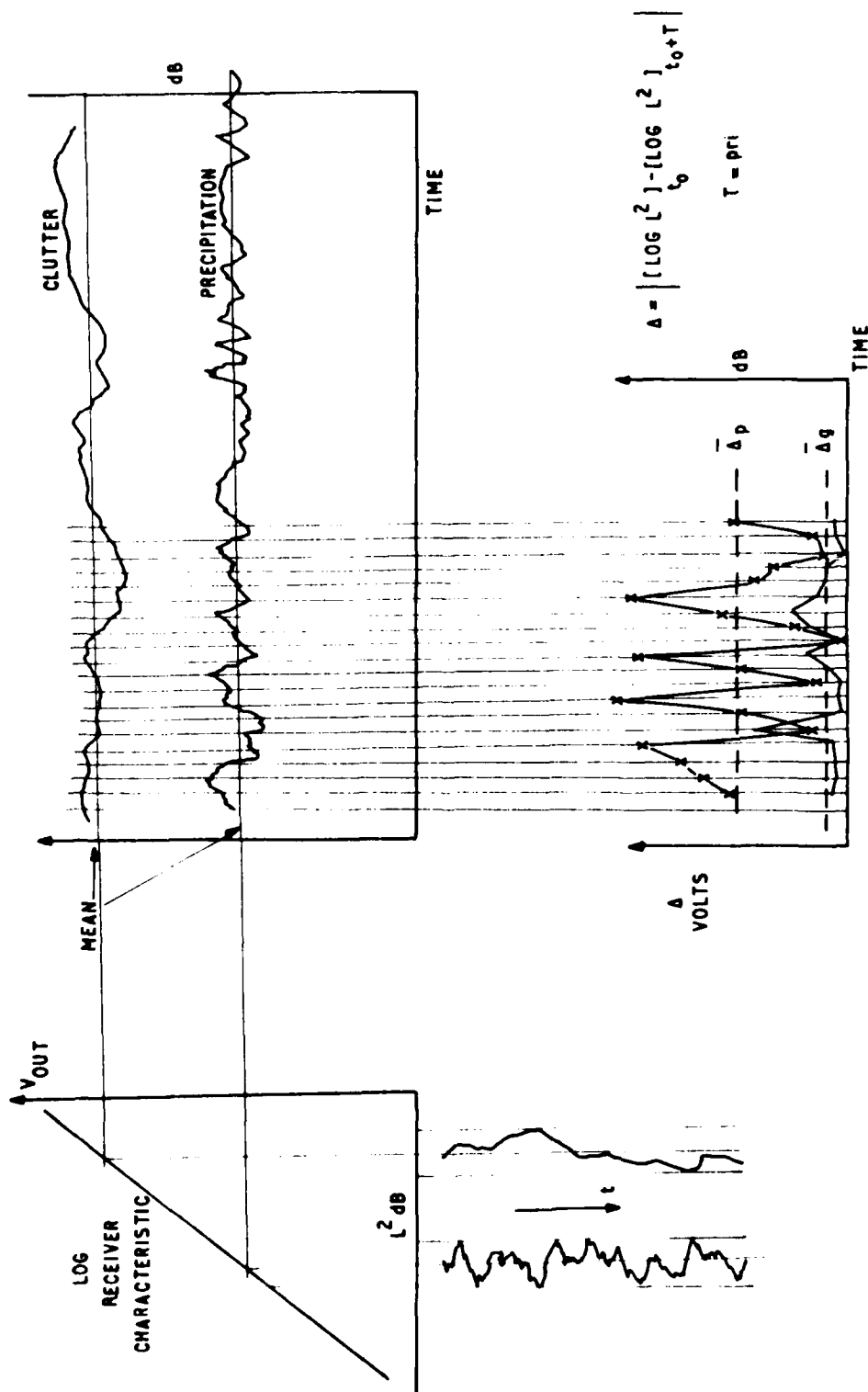
GROUND TARGET.

FIG 3.2

ILLUSTRATION OF TYPICAL INPUT SIGNALS TO THE CLUTTER/PRECIPITATION
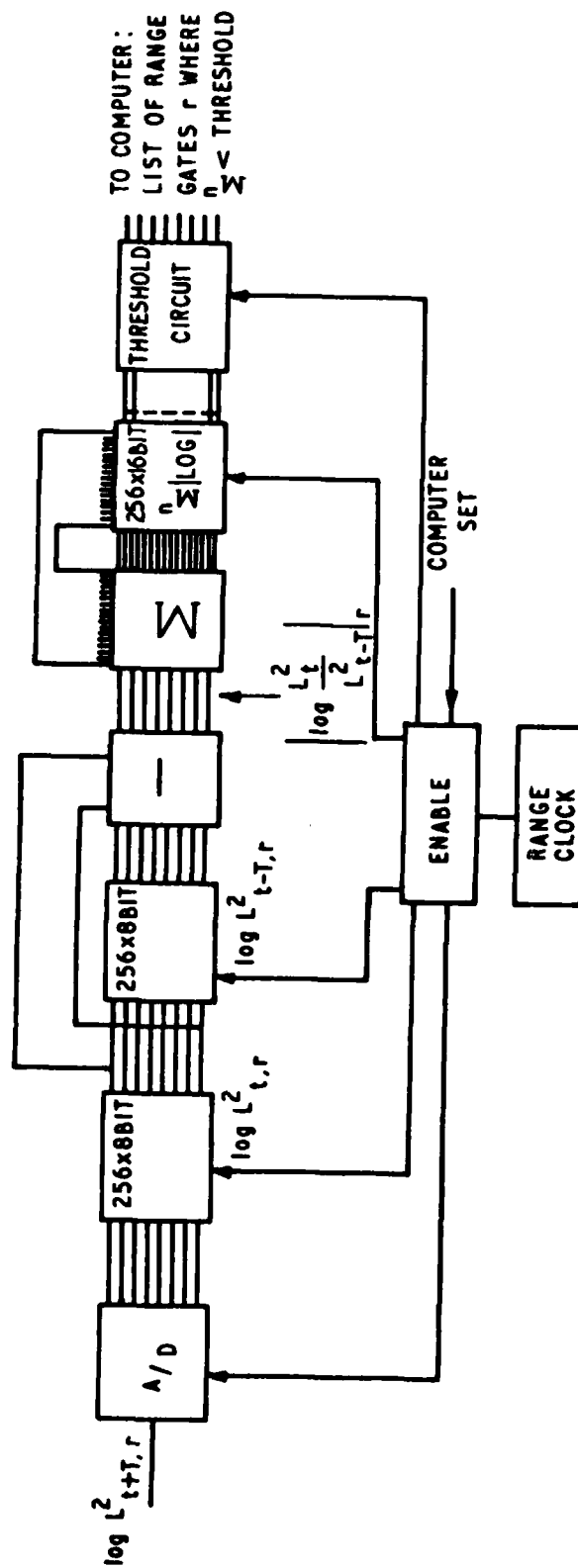
DISCRIMINATOR.   RR/R 31/9989

FIG. 3.3

CLUTTER/PRECIPITATION DISCRIMINATOR LOGIC CIRCUIT.
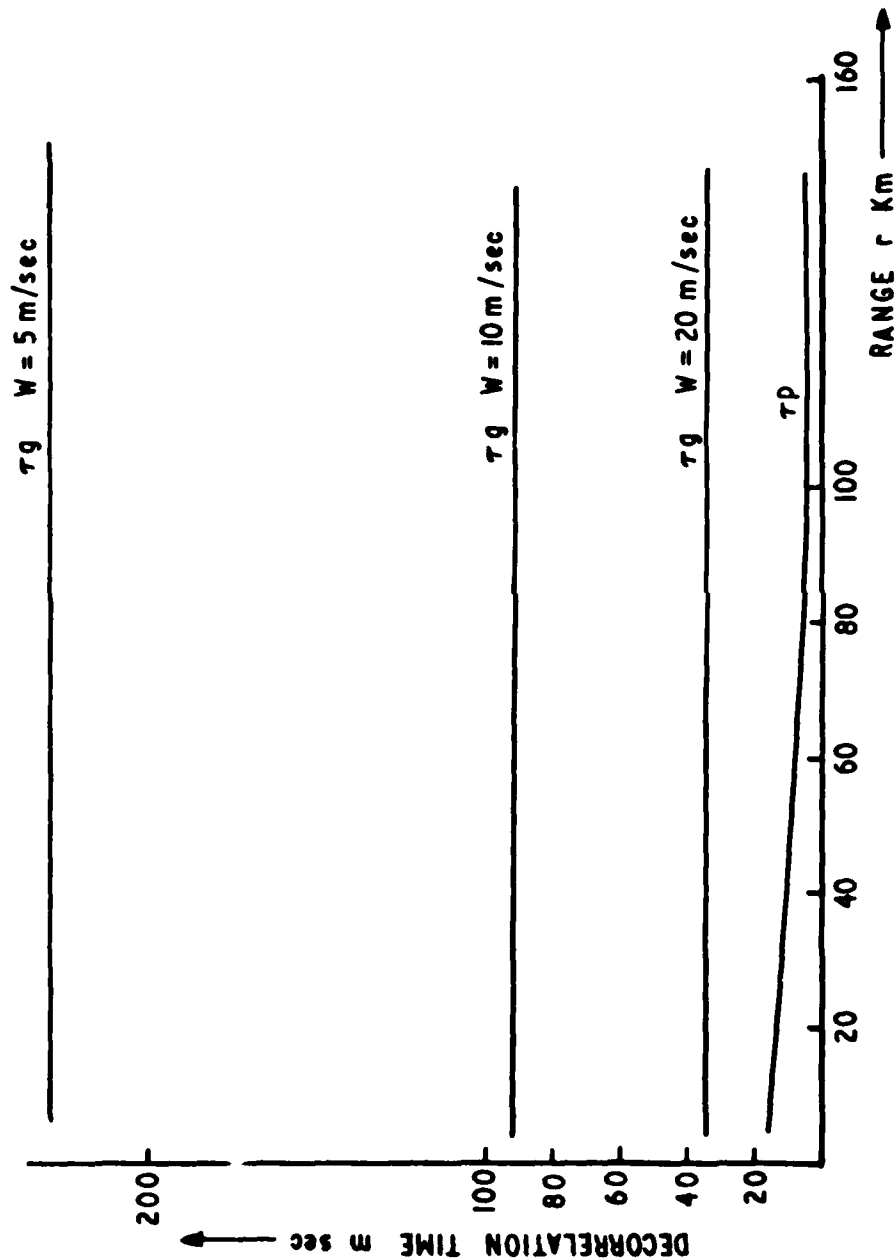
RR R 3/19979

FIG. 3.4

DECORRELATION TIME FOR PRECIPITATION AND CLUTTER AS A
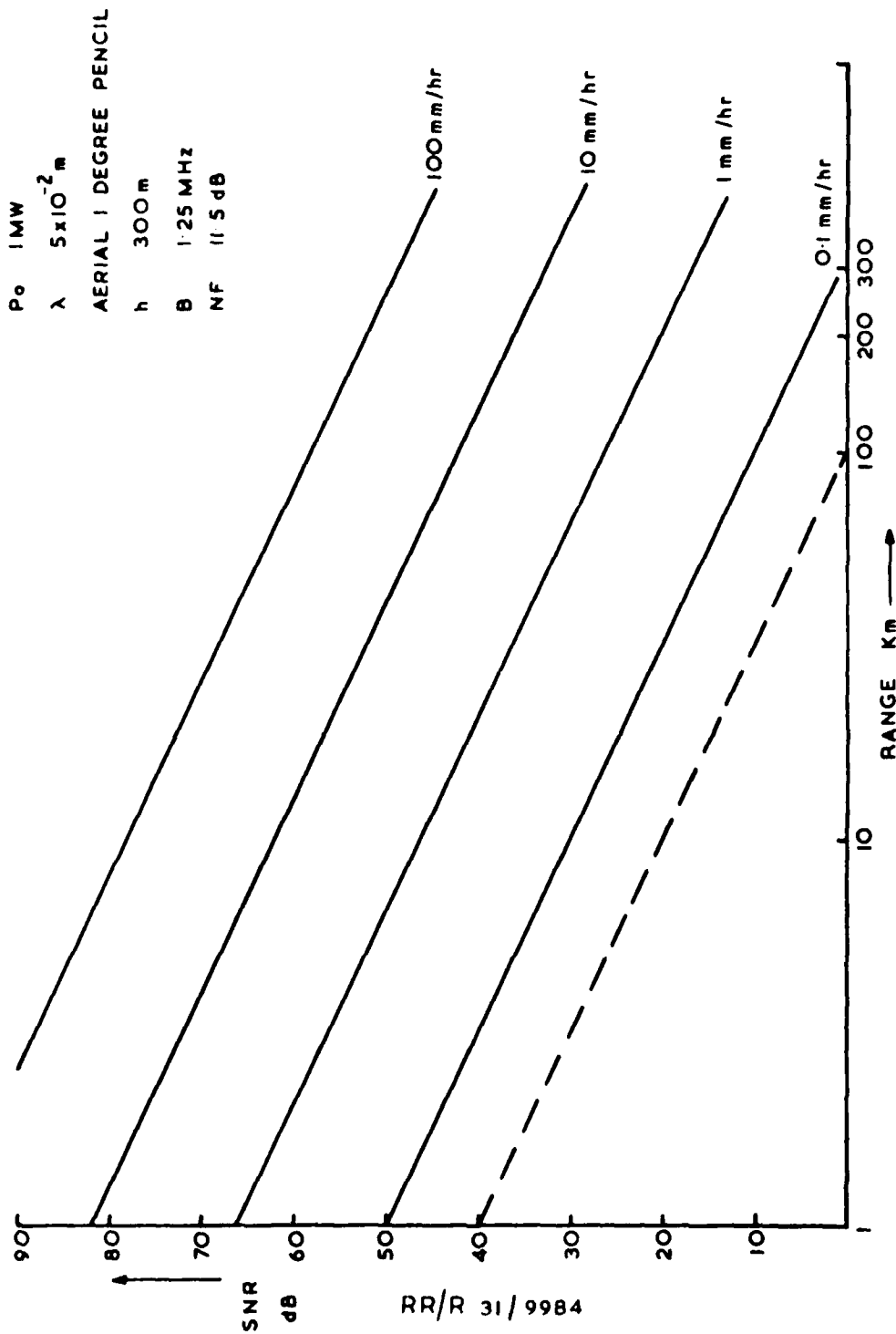
FUNCTION OF RANGE AND WIND SPEED.

FIG. 1.

PERFORMANCE CHARACTERISTICS FOR 5CM. WEATHER RADAR WITH PARAMETERS SHOWN.

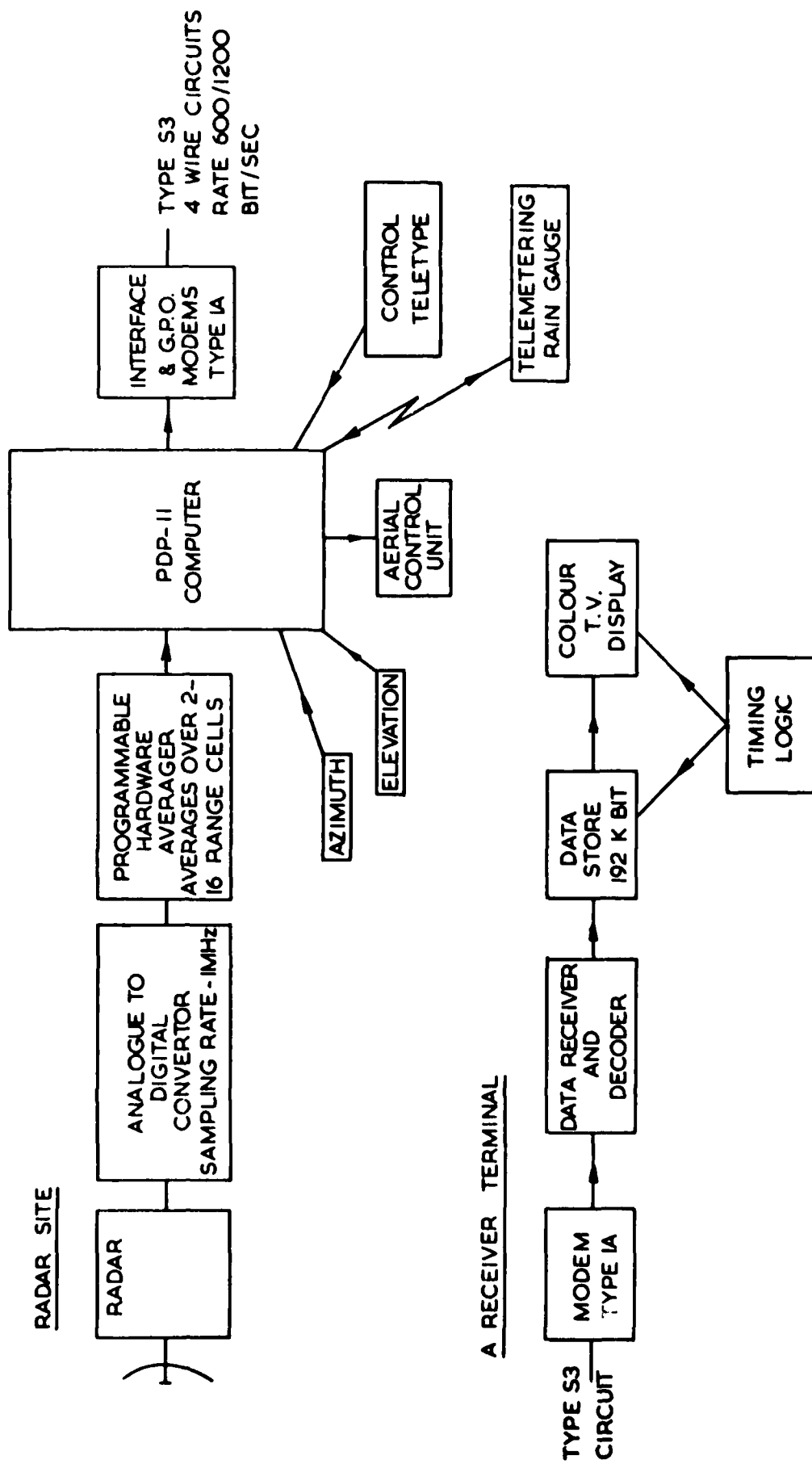DOTTED CURVE WILL BE THE BASELINE FOR SIGNALS RANGE-NORMALISED TO 100KM

RR/R 31/9984

RADAR SITE

RADAR → ANALOGUE TO DIGITAL CONVERTOR SAMPLING RATE - IMHz → PROGRAMMABLE HARDWARE AVERAGER AVERAGES OVER 2-16 RANGE CELLS → PDP-II COMPUTER

PDP-II COMPUTER → INTERFACE & G.P.O. MODEMS TYPE IA → TYPE S3 4 WIRE CIRCUITS RATE 600/1200 BIT/SEC

CONTROL TELETYPE
TELEMETERING RAIN GAUGE
AERIAL CONTROL UNIT
AZIMUTH
ELEVATION

A RECEIVER TERMINAL

TYPE S3 CIRCUIT → MODEM TYPE IA → DATA RECEIVER AND DECODER → DATA STORE 192 K BIT → COLOUR T.V. DISPLAY

TIMING LOGIC

FIG. 2.

OVERALL OUTLINE OF PROTOTYPE SYSTEM

RR/R 31/9985

AZIMUTH/TIME

RANGE / TIME
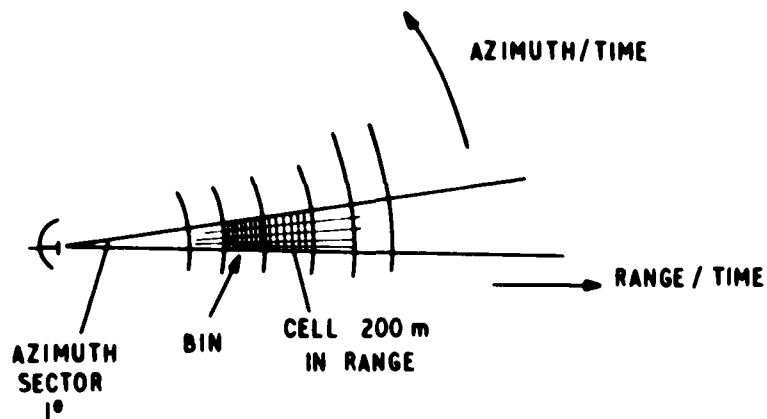
AZIMUTH
SECTOR
1°

BIN

CELL 200 m
IN RANGE

FIG. 3A.

THE DIVISION OF EACH AZIMUTH SECTOR INTO RANGE
CELLS AND BINS BY THE ADC AND HARDWARE AVERAGER,
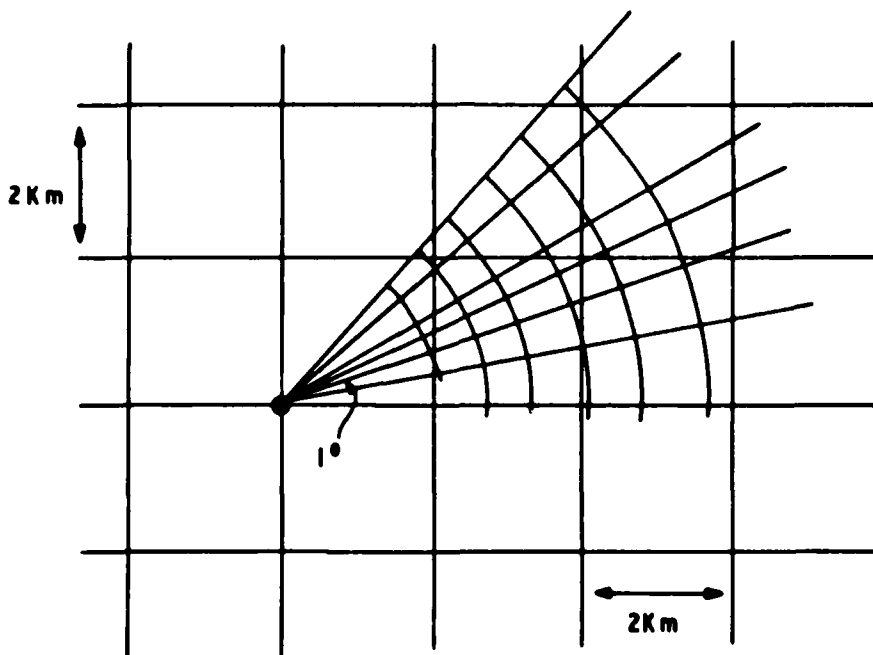AND INTO AZIMUTH CELLS BY THE NUMBER OF RADAR
TRANSMISSIONS ACCEPTED.

2Km

1°

2Km

FIG. 3B

ILLUSTRATION OF THE CONVERSION FROM POLAR TO
2KM. CARTESIAN CO-ORDINATES .A SIMILAR COMPUTATION
APPLIES FOR CONVERSION TO 5*5 KM GRID.

RR R 3/19977

```
AZIMUTH                 RANGE CELL NUMBER (OCTAL)

241 | 005 010 012 014 024 024 032 032 037 037 072 100 126 126 0

242 | 005 010 013 013 024 025 031 032 037 053 071 073 075 100 124 126 0

243 | 005 010 013 014 022 025 031 034 037 041 043 053 072 073 076 100 124 126 0

244 | 006 007 013 014 022 024 030 035 040 040 042 047 051 053 072 073 124 126 0
```

FIG 4   PRINT OUT OF A CLUTTER MAP (CLUMAP) STORED IN COMPUTER
MEMORY.THIS PRINT OUT APPLIES TO THE LLANDEGLA RADAR ELEVATION ANGLE
0.5 DEGREES AND AZIMUTHS BETWEEN 241 AND 244 DEGREES.
NUMBERS ARE OCTAL AND REFER TO RANGE CELL NUMBERS WHERE ONE RANGE CELL
IS 750 METRES.CLUTTER EXISTS BETWEEN PAIRS OF RANGE CELLS.
A ZERO INDICATES NO FURTHER CLUTTER AT THAT AZIMUTH.

FIG. 4.

FIG 5

RR/R 3/1-1441

FIG 6
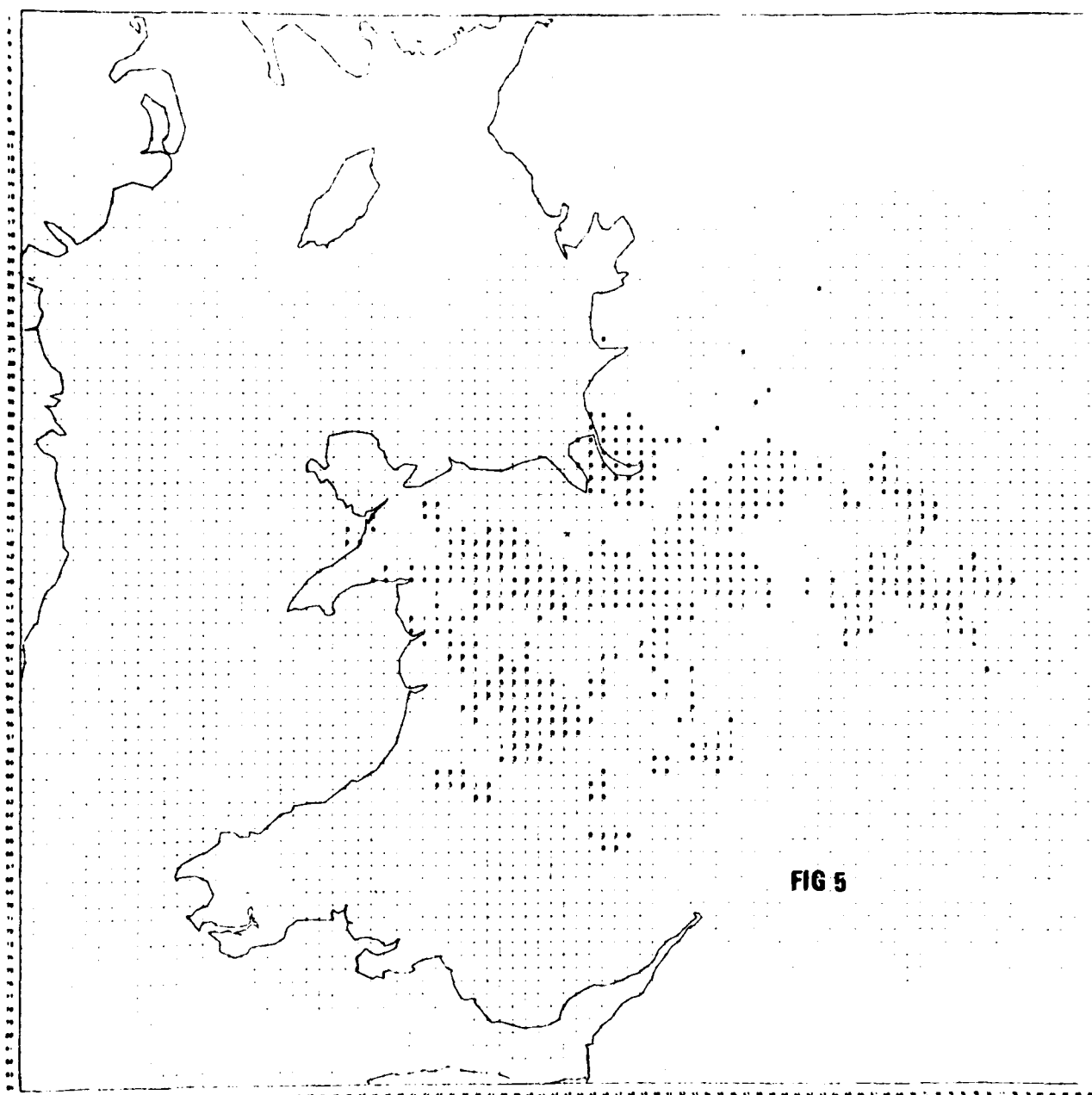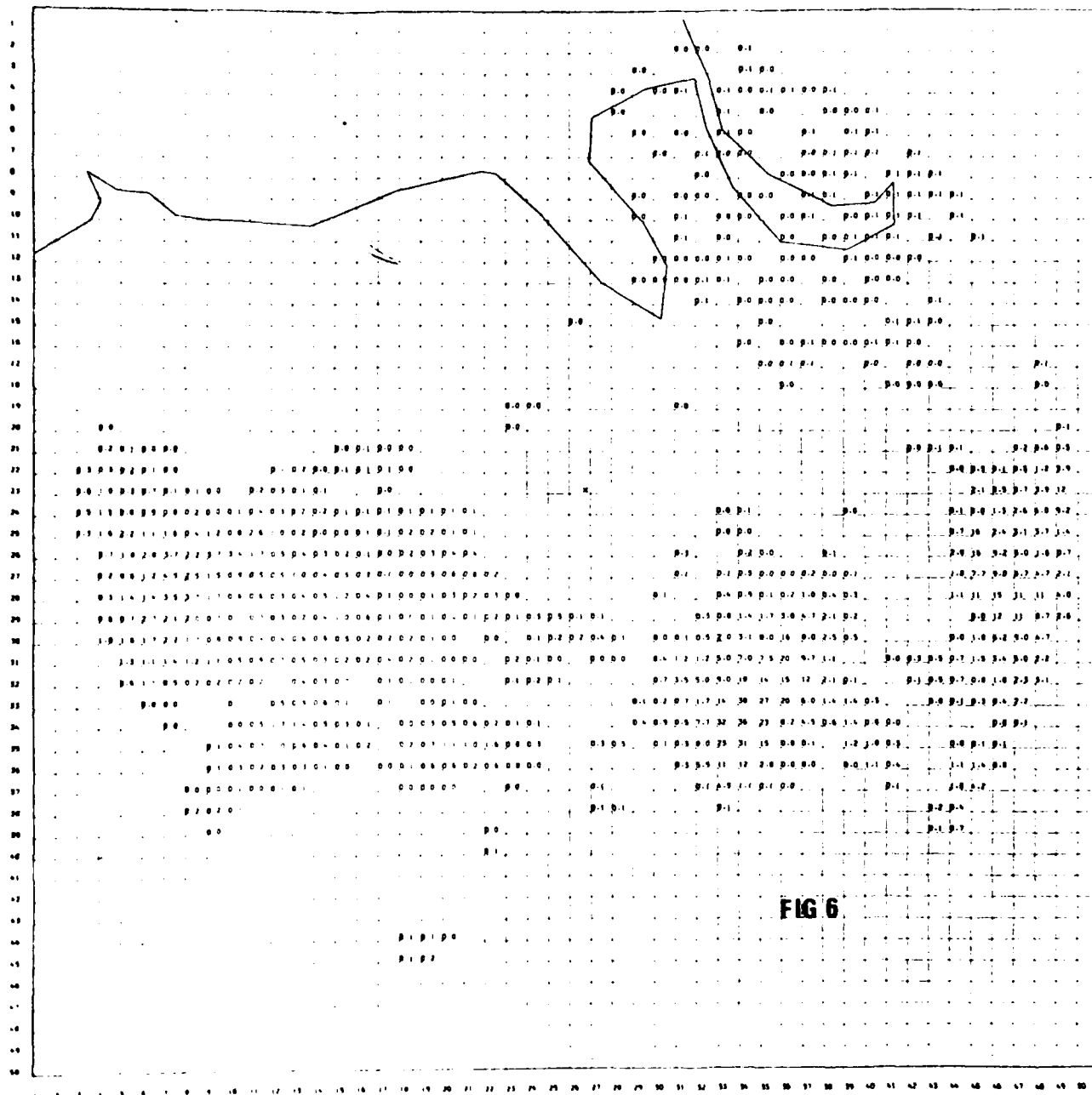
SEVERN-TRENT
WATER AUTHORITY

SEVERN BASIN
RADAR COVERAGE

GRID DEFINITION OF
SUB-CATCHMENTS-(1)SHROPSHIRE PLAIN

KEY

——— SEVERN BASIN WATERSHED

– – – SELECTED SUB-CATCHMENT
WATERSHEDS IN SEVERN
BASIN

FIG 7

DATA BYTES

COLOUR WORD 1 / COLOUR WORD 2 / DATA BYTE CODE

| START BIT | x | x | x | x | x | 0 | 0 | STOP BIT |

LSB ← R G B R G B → MSB

FRAME BYTES

FRAME No / FRAME BYTE CODE

| START BIT | x | x | x | x | 1 | 1 | 1 | STOP BIT |

LSB → MSB

LINE BYTES

LINE BYTE CODE

| START BIT | 1 | 1 | 0 | 0 | 0 | 0 | 1 | STOP BIT |

LSB → MSB

X IS LOGICAL I OR 0 DEPENDING UPON THE DATA. OR FRAME NUMBER BEING TRANSMITTED

FIG 8B

BIT ORGANISATION OF MODEM BITES

RR/R 31/ 9990

FIG. 8A.
GENERAL DATA STORE ORGANISATION.

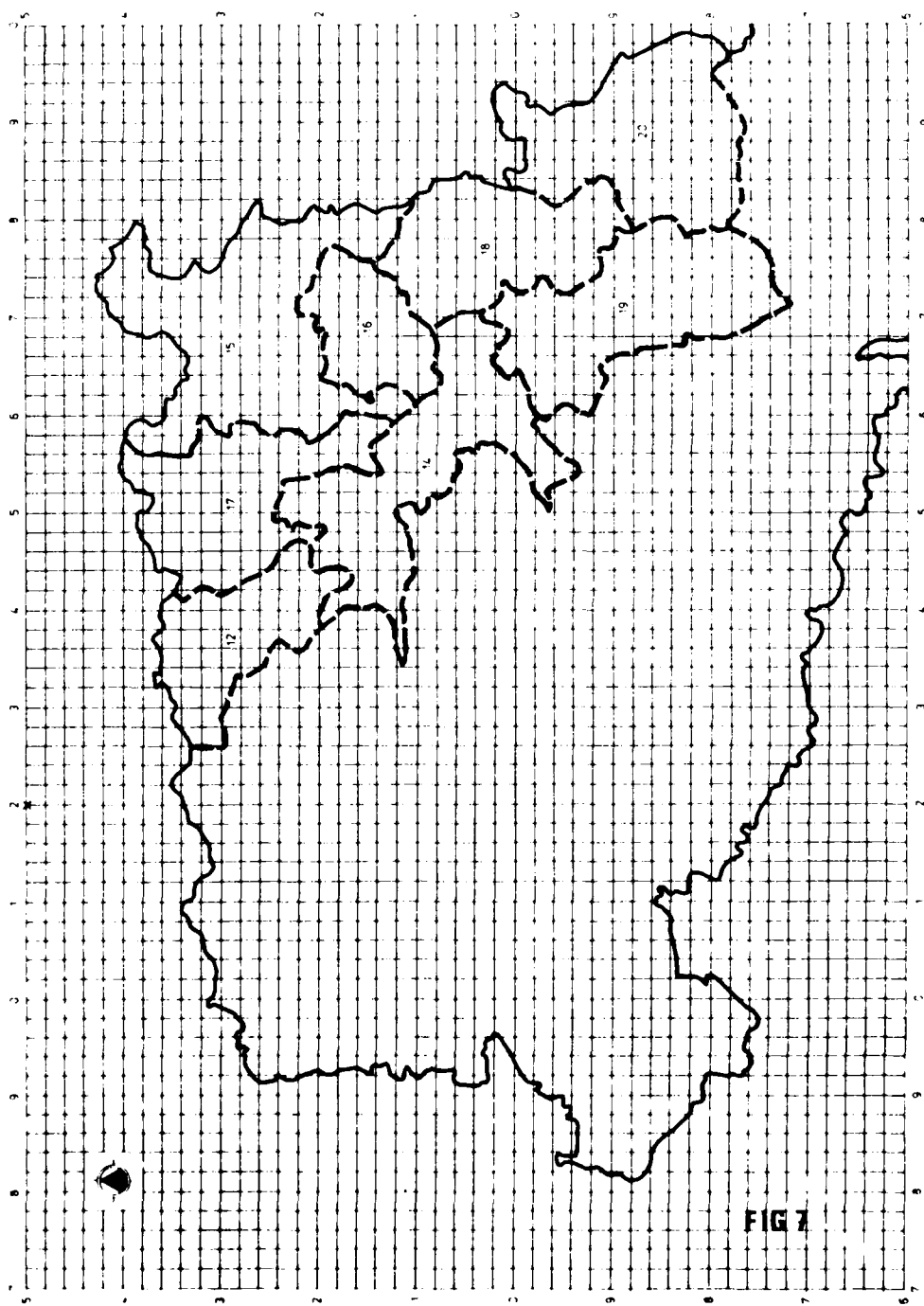* RECIRCULATING CLOCK REQUIRED FOR D.S.R. MEMORIES ONLY

→ DATA PATH

Fig 9   Photograph of Llandegla Display 15.11.75

END

DATE
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